



Effect of Laxmanpur Barrage on the River System - A Case Study through Multi-Temporal Satellite Remote Sensing Data

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General Note

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ABSTRACT

The Rapti River is meandering river, consisting of a variable number of meander bends, which change their locations and sizes each year. Understanding river behaviour in u/s and d/s of hydraulic structures help in their proper planning, design, and maintenance. Hydraulic analysis is made of the river behaviour in u/s and d/s of hydraulic structures like barrages and spurs as a result of sediment deposition in u/s and inadequate energy dissipation due to skewed hydraulic jump in d/s. To solve this problem, a study i.e. effects of Laxmanpur barrage on the river system has been done through multi-temporal Landsat satellite data from 1972 to 2020 provided by USGS. The river widths and sediment deposition of d/s and u/s from the Laxmanpur barrage before and after the installation of the barrage were examined. The river width before the installation of barrage is more-or-less equal in u/s and d/s. It has going to start disturbing when barrage work started in 1981. It has been taken a long time (till 2006, approx. 25 years) to re-adjust its characteristic state.

Keywords: Laxmanpur barrage, Rapti River, bank protection structures, remote sensing, and GIS

1. INTRODUCTION

Study of hydraulic structures such as barrage, embankments, and spurs structures can provide valuable information on their influences on morphological processes in natural rivers. These structures usually used for bank protection and formation of deep navigation channel can locally create complex flow patterns, reduce flow velocities, and also increase the flood levels. Traditionally, embankments, and spurs structures are impermeable or solid structures, which are usually used to increase water depth for navigation purposes, to protect riverbank and to restore the natural river scenery (Klingeman et al., 1984; Shields et al., 2003; Wang et al., 2007). In addition to that these structures are usually generated fluid jets, leading to local scour downstream (Bormann et al., 1991; Lu et al., 2013; Guan et al., 2015; Sattat et al., 2017).

A proper understanding of the behavior of the river in the vicinity of hydraulic structures is of utmost importance in their planning, design, and maintenance in addition to the protection of the structures. They disrupt normal waterways. The flow fields that used to prevail before their construction are replaced. There is an afflux of the channel on the backwater effect upstream. Hydraulic and energy gradients are reduced. The sediment carrying capacity of the stream is reduced, leading to the deposition of sediment upward. At the bottom of the structures, erosion occurs due to high sediment leaving water with low sediment load and residual kinetic energy flow. Uncontrolled aggradation and degradation often lead to serious problems of river training (Mazumder, 2011).

2. ABOUT THE STUDY AREA

Laxmanpur barrage (Rapti barrage) is situated at $27^{\circ}51'52.438''$ N latitude and $81^{\circ}48'50.164''$ E longitude on Rapti River in Shravasti district of Uttar Pradesh, India. The salient features of the Laxmanpur barrage (Rapti barrage) has been collected from CWC Water Resource Information System (CWC, 2018), and shown in Table . Location map of Laxmanpur barrage (Rapti barrage) is shown in Figure 1.

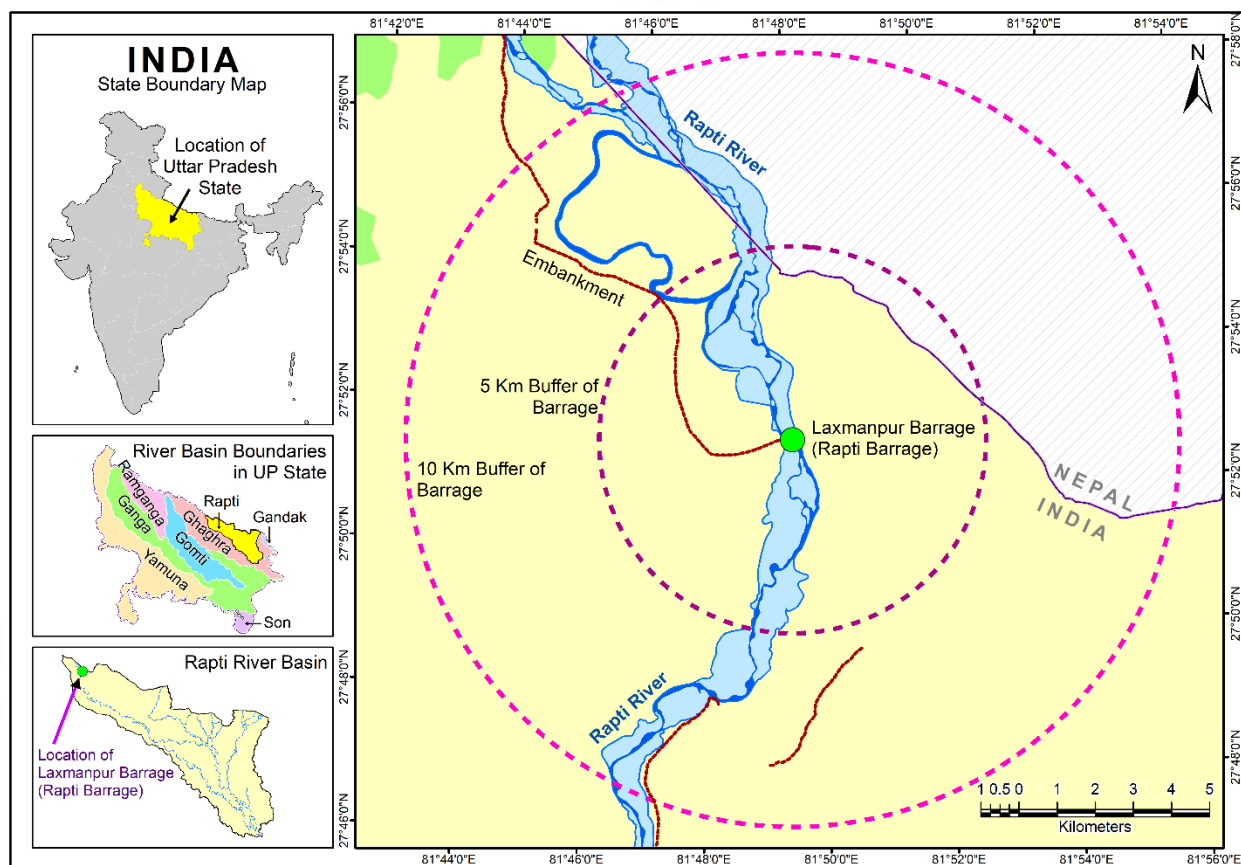


Figure 1. Location Map of Laxmanpur Barrage (Rapti Barrage), Uttar Pradesh, India

Table 1 Salient Features of Laxmanpur Barrage (Rapti Barrage)

S. No.	Features	Details
1.	Name of the structure	Rapti Barrage
2.	Construction period	1981-1985
3.	Nearest city	Bahraich
4.	District	Shrawasti
5.	State	Uttar Pradesh
6.	Name of River	Rapti
7.	Basin	Ganga
8.	Design flood (Cumec)	4990
9.	Length of Barrage and Anicut (m)	284.5
10.	No. of bays (i.e. number of openings)	15
11.	Width of Bay (m)	18
12.	Type of spillway gate	Other
13.	Crest Level (m)	125
14.	Pond level (m)	127.7
15.	Under sluice bay - Number	4
16.	Gates for under sluice -Size (m)	14*18*3
17.	Means for dissipating energy (Hydraulic)	Dentated sill device

Source: India-WRIS

3. DATA USED AND SOURCES

In this study, various basic thematic layers were created from different source including map, field study, satellite imageries and secondary data. Using ArcGIS 10.7 software tools, several maps were prepared including river bankline, hydraulic structures - embankments, spurs / studs, bridge, and barrages. Data used, and description of data sources are shown in Table 1.

Table 1 Data Used and Description of Data Sources

S.No.	Data layers / maps	Description of data sources
1.	Satellite remote sensing data	Multi-temporal, multi-spatial, and multi-spectral satellite remote sensing data from 1975 to 2019 have been downloaded for entire Rapti river basin, India from U.S. Geological Survey (USGS), Earth Explorer. Source: http://earthexplorer.usgs.gov Landsat-2 MSS: 1975 Landsat-3 MSS: 1980 Landsat-5 TM: 1988, 1990, 1998, 2004, 2006, 2007, 2008, 2009, 2010 Landsat-7 ETM+: 2001, 2011, 2012 Landsat-8 OLI: 2013, 2014, 2015, 2016, 2017, 2018, 2019
2.	Barrage details	The details of Laxmanpur barrage (Rapti barrage) has been taken from India-WRIS website. Source: http://indiawriss.gov.in/wris/#/

4. RESULT AND DISCUSSION

4.1. Laxmanpur Barrage (Rapti Barrage) on Rapti River

Human impacts do not directly alter the fundamental hydraulic and geomorphic processes such as the mechanics of sediment transport, erosion, and deposition along rivers. However, human disturbance modifies the spatial distribution (pattern, extent, and linkages) and rate (accentuated / accelerated or decelerated / suppressed) of these processes, often inducing profound changes to river morphology, whether advertently or otherwise. Some processes and landscape responses now happen more often in more

places than they did prior to human disturbance. Human modifications to biophysical attributes of river systems can be direct or indirect. Direct channel changes are water storage in reservoirs behind dams or barrage, Water diversion schemes, channelization including flood control works, levee and stop-bank construction, bed / bank stabilisation structures, etc. Design and construction of water development and river training structures without having a thorough assessment of river hydraulics increase risk and vulnerability. Such structures obstruct the flow of rivers resulting widespread inundation in upstream and downstream areas. Disturbance to water and sediment transfer impacts directly on river structure and function both upstream and downstream of a barrage.

Laxmanpur barrage (Rapti barrage) was constructed by the Government of India during 1981-1985 for the purpose of providing irrigation in the surrounding agricultural fields. Barrage is a point-source form of disturbance; it makes considerable off-site effects because barrage change the longitudinal connectivity and base-level conditions of the river. The main problems in the study area due to annual flood inundations, bank erosion, high sediment load and river course shifting. Extreme flood events were reported in upstream and downstream of Laxmanpur barrage (Rapti barrage) is listed in Table 3.

Table 2. Flood Event Years of Upstream and Downstream of Laxmanpur Barrage (Rapti Barrage) (1970-2019)

Location of flood event	Flood event years*/#								
Nepal / Upstream of Laxmanpur barrage (Rapti barrage)	-	-	1984	-	1989	1998	-	2007	2017
India / Downstream of Laxmanpur barrage (Rapti barrage)	1971	1974	-	1980	-	1998	2001	2007	2017

*Flood event years after 1970, # Source: National Institute of Disaster Management (NIDM)

With reference to several studies i.e. Bhusal (2004); Adhikari (2013); Gautam et al., (2013); Shrestha (2016) and institutional reports i.e. Osti (2008); NDRI (2012); Sanstha (2014); Devkota (2014), Nepalese have claimed that the Laxmanpur barrage (Rapti barrage) has been constructed in violation of international norms. Nepalese communities have communicated that, according to international norms the barrage can be constructed at 16.5 Km from Nepal border, while it is just about 4.5 Km from the nearest inundation point on Nepal. They have also blamed that the flood inundations, bank erosion, high sediment load and river course shifting are happening in Nepal due to Laxmanpur barrage (Rapti barrage). The inundation problem has been worsened by the construction of Laxmanpur barrage (Rapti barrage) and Kalkaluwa afflux bund (embankment) in India (due to obstruction of natural drains and flows from west Rapti river) (UNDP, 2009). I think, it is not a corrected statement, because Rapti river basin (Indian and Nepal part) is located in flood prone area. The following points are also support to our statement (Embassy of India, Kathmandu, 2000).

- The Laxmanpur barrage (Rapti barrage) is situated 4.5 Km downstream of the India-Nepal border, and the submergence is within Indian Territory.
- The barrage is a structure for diverting non-monsoon flows, it is not a storage reservoir, it allows for free passage of water during floods, there is no increase in the water level or inundation during such period.
- The pond level (full reservoir level) of the Laxmanpur barrage (Rapti barrage) is 127.60 m amsl, while the general ground level on the Nepalese side is 131.00 m amsl, which is higher than the pond level.
- The barrage is not yet operational as its gates have not been lowered.

An analysis was made on the morphological alterations, which have been taking place after the deployment of the barrage. I examined the river stretch, 10 km upstream and 10 km downstream from the Laxmanpur barrage (Rapti barrage) to analyze the possible impact of the barrage on the river system.

Multi-temporal Landsat satellite imageries for the years 1975, 1980, 1988, 1990, 1998, 2001, 2004, and 2006-2019 for the pre-monsoon periods were examined. The years 1975 and 1980 are the pre-installation periods while the rest of the years (1988, 1990, 1998, 2001, 2004, 2006-2019) are the post-installation periods (Figure 2).

4.2. Impact on Upstream River Morphology

In the year 1975 and 1980 (pre-installation period), the river was running in a meandering pattern shifting to the right in the upstream part. After the deployment of the barrage, the upstream river got straightened up due to the impact of the barrage as seen in the images of 1988 and 1990. In the subsequent years, the river started to take a meandering pattern again.

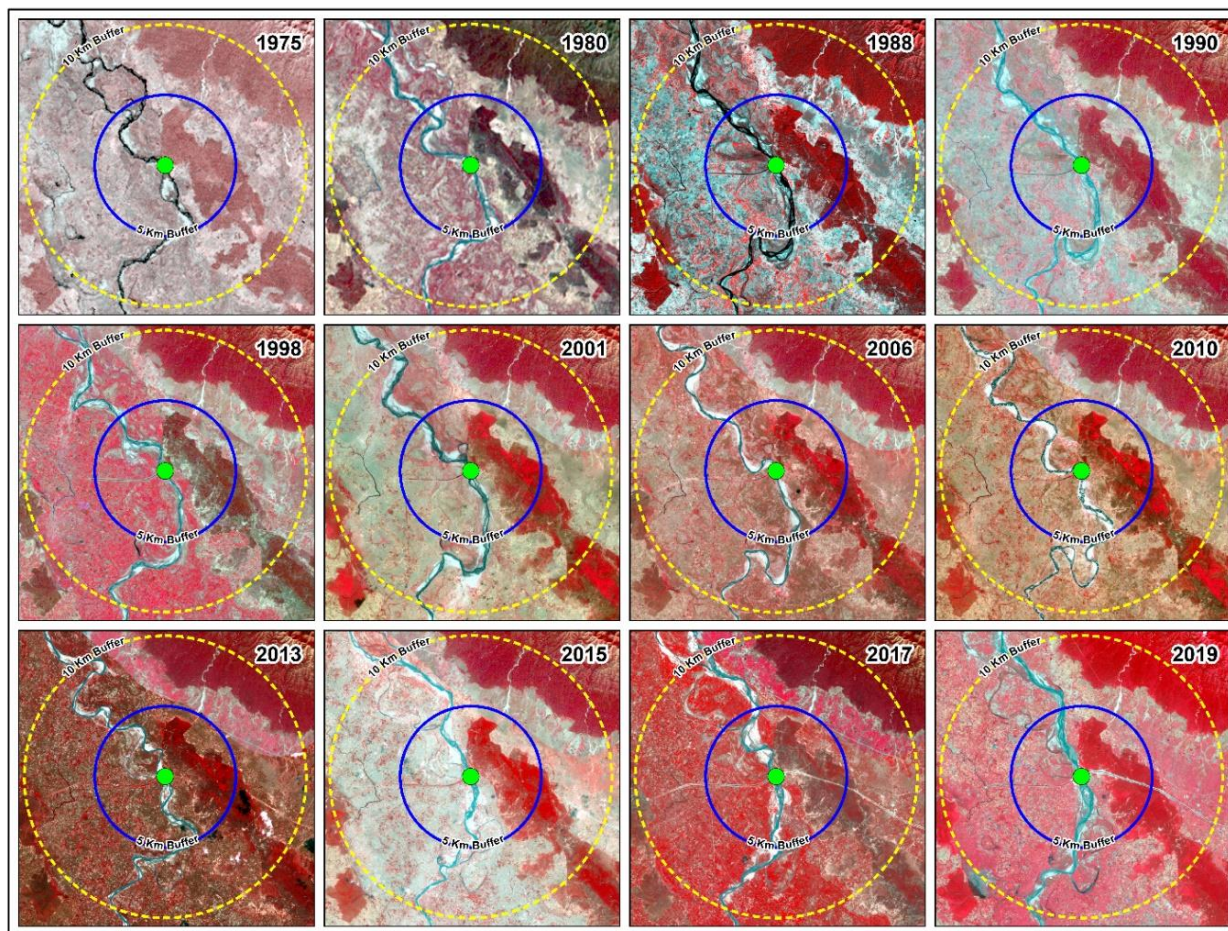


Figure 2. Multi-Temporal Landsat Satellite Imageries of Laxmanpur Barrage (Rapti Barrage) (1975-2019)

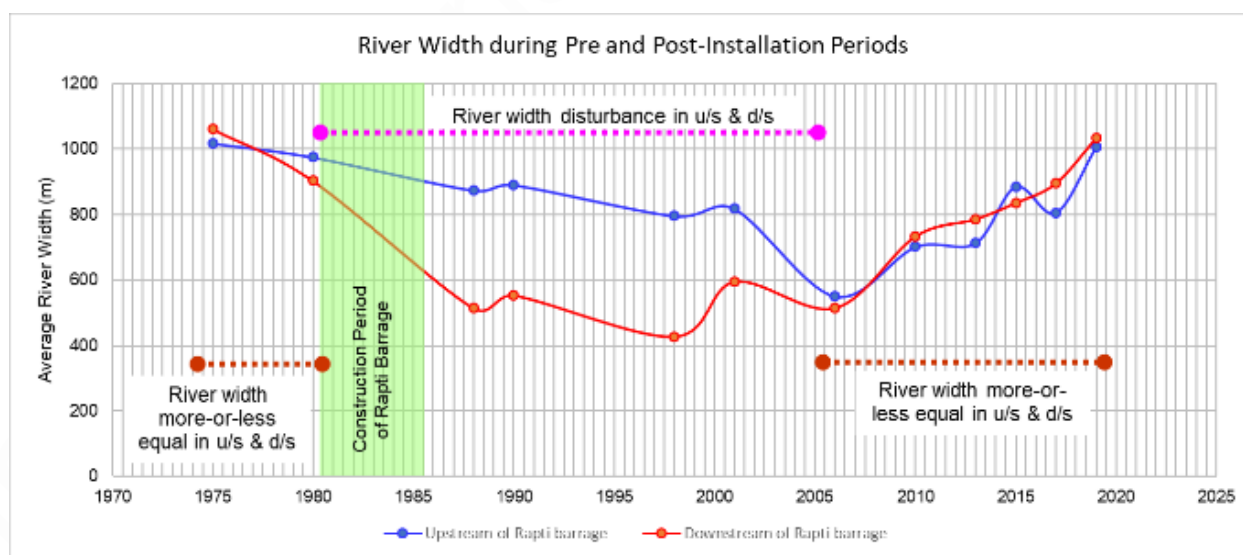


Figure 3. River Width during Pre-and-Post Installation Periods of Laxmanpur Barrage (Rapti Barrage)

4.3. Impact on Downstream River Morphology

Prior to the construction of the barrage, the river took a 90° turn to the right at about 5 km downstream from barrage. After deployment of the barrage, the river moved to the left, but it could not move further to left due to the presence of signification riparian vegetation and afforestation work (as evident from green and geometric pattern in satellite imageries in 1988 image). After

the obstruction by the riparian vegetation, the river meandered in a zigzag pattern after passing the vegetative zone approx. about 5 km downstream. In the subsequent years, the downstream river moved gradually away from the vegetation zone, but the downstream meandering continues but by 2017 the river became less meandering.

The river widths of downstream and upstream from the Laxmanpur barrage (Rapti barrage) before and after the installation of the barrage were examined. The river width before the installation or construction of barrage is more-or-less equal in u/s and d/s. It has going to start disturbing when barrage work started in 1981. It has been taken a long time (till 2006, approx. 25 years) to re-adjust its characteristic state. After 2006, the balance of river width in u/s and d/s is more-or-less equal (Figure 3), because geomorphic response times following the emplacement of river engineering works depend on the types of works installed and the extent to which they alter flow and stream power, sediment supply and vegetation cover. It may take 20 to 100 years to attain this new characteristic state.

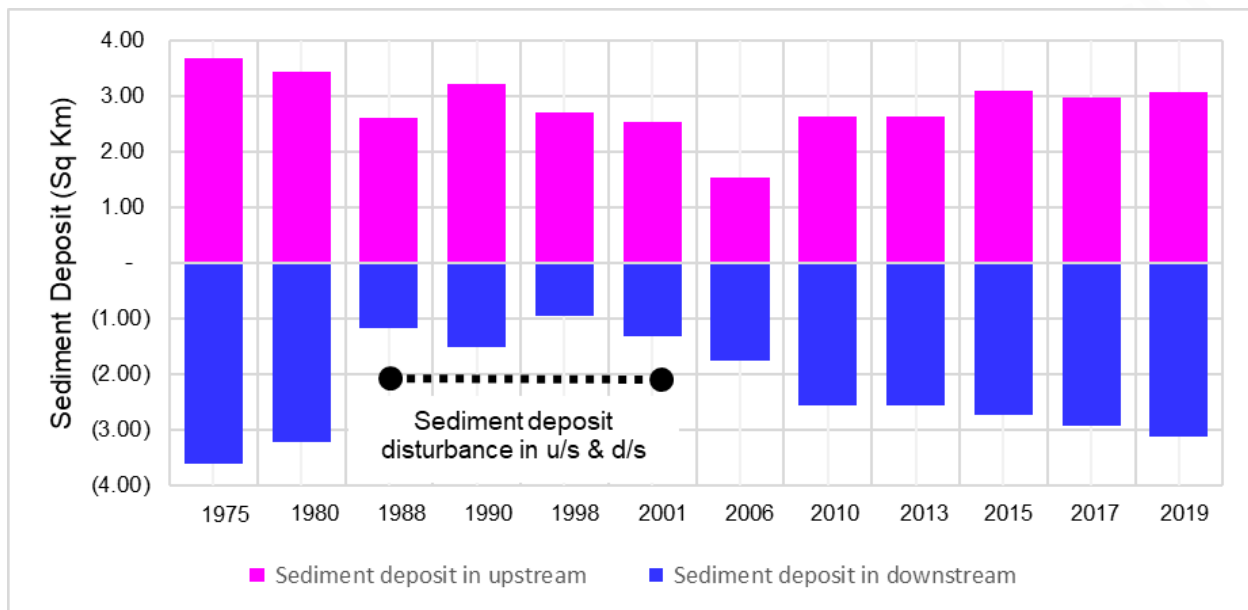


Figure 4. Sediment Deposit in u/s and d/s of Laxmanpur Barrage (Rapti Barrage)

I have also examined the sediment deposit in downstream and upstream from the Laxmanpur barrage (Rapti barrage), and I have found that the deposition of sediment is disturbed from 1981 to 2005 (approx. 25 years). In that period deposition is more in upstream and the reverse in downstream. I have noticed that the sediment deposition pattern in u/s and d/s is more-or-less equal from 1975 to 1980 (before installation of the barrage), and from 2006 to 2019 (Figure 4), that also supports our above-stated statement.

4.4. What Happen when Laxmanpur Barrage (Rapti Barrage) will Operational?

The construction of Laxmanpur barrage (Rapti barrage) was completed in 1986, but it has not been operated till date. When the Laxmanpur barrage (Rapti barrage) will start the operation, it will affect the river morphology in upstream and downstream of barrage. In upstream of barrage, it will reduce velocities of water, due to this silt and sediment will accumulate at a higher rate, lowering the river height and decreasing the river speed leading to lateral expansion of the river or widening of the channel (braiding of river streams), suspended silt particles in the river water settle down. Relatively silt and sediment-free water will be released through the spillway, have the energy to move sediment in downstream, causes erosion in downstream. This 'hungry water' expends its energy by eroding the channel bed and banks. Bed incision and river widening may reduce over the timeframes ranging from 20 to over 100 years, when river will re-adjust its new characteristic state.

5. CONCLUSION

In this paper, remote sensing and GIS techniques have been used intensively. The free Landsat series satellite imageries from 1972 to 2020 provided by USGS is now used all over the world. With this type of satellite imagery, we can generate and analyze the time series data of the last 50 years. These datasets have been used for study of effect of Laxmanpur barrage (Rapti barrage) on the river system. The river widths and sediment deposit of d/s and u/s from the Laxmanpur barrage (Rapti barrage) before and after the installation of the barrage were examined. The river width before the installation or construction of barrage is more-or-less equal in

u/s and d/s. It has going to start disturbing when barrage work started in 1981. It has been taken a long time (till 2006, approx. 25 years) to re-adjust its characteristic state. After 2006, the balance of river width in u/s and d/s is more-or-less equal, because geomorphic response times following the emplacement of river engineering works depend on the types of works installed and the extent to which they alter flow and stream power, sediment supply and vegetation cover. It may take 20 to 100 years to attain this new characteristic state.

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Conflict of Interest:

The author declares that there are no conflicts of interests.

Peer-review: External peer-review was done through double-blind method.

Data and materials availability: All data associated with this study are present in the paper.

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